Diffusion dans les réseaux sans fil en utilisant des filtres à mémoire constante

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Diffusion dans les réseaux sans fil en utilisant des filtres à mémoire constante[†]

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Dans cet article nous nous intéressons au problème de la diffusion dans les réseaux sans fil. Nous étudions un modèle particulier de système où les noeuds disposent localement d'un espace de mémoire constant leur permettant d'éviter des collisions lors de transmissions concurrentes. Nous étudions deux variantes de la diffusion : diffusion avec et sans accusé de réception (l'initiateur de la diffusion est notifié de la terminaison du processus de diffusion). Nous nous intéressons tout d'abord à une classe particulière de réseaux issue de nos travaux récents dans le cadre des réseaux corporels. Pour cette classe de réseaux nous proposons des algorithmes de diffusion utilisant des filtres à 1-bit de mémoire pour la diffusion sans accusé de réception et 2-bits de mémoire pour la diffusion avec. Nos algorithmes se terminent en $2D$ rondes de communication où D est l'excentricité de l'initiateur de la diffusion. Nous poursuivons notre étude en généralisant la méthodologie aux graphes quelconques. Nos solutions améliorent la complexité mémoire de l'état de l'art.

Mots-clefs : Label, Diffusion, Réseau sans fil

1 Introduction

Broadcast is the most studied communication primitive in networks and distributed systems. Broadcast ensures that once a *source node* (a.k.a. the broadcast initiator) sends a message then all other nodes in the network should receive this message in a finite time.

Our study follows the recent work [EGMP19] that addresses the broadcast problem for wireless multi-hop networks at the application layer. More specifically, we are interested in deterministic solutions for broadcasting messages based on the use of extra information or advice (also referred as *labelling*) precomputed before the broadcast invocation. Authors propose in [EGMP19] the abstract model of arbitrary wireless multi-hop network, and then two corresponding broadcast solutions :

1) *a labelling scheme with **2-bits** advice for broadcast without acknowledgment and the corresponding broadcast algorithm which finishes in **2n-3** rounds.*

2) *a labelling scheme with **3-bits** advice for broadcast with acknowledgment and the corresponding broadcast algorithm which finishes in **3n-4** rounds.*

where n is the number of nodes in the network. Note that when we use labelling schemes, nodes record less information than in the case of centralized broadcast, where nodes need to know complete network information [KP07]. Compared with the existing solutions for deterministic distributed broadcast the use of labelling schemes improves the time complexity [CMX09].

Contribution : Our work is in the line of research described in [EGMP19]. We first propose a new family of network topologies, called *Level-Separable Networks* issued from our research, *Wireless Body Area Network* (e.g. [BPB17b], [BPB17a]). We propose then two broadcast solutions for level-separable networks :

1) *a labelling scheme with **1-bit** advice for broadcast without acknowledgment and the corresponding broadcast algorithm which finishes in **2D** rounds.*

2) *a labelling scheme with **2-bits** advice for broadcast with acknowledgment and the corresponding broadcast algorithm which finishes in **2D** rounds.*

where D is the eccentricity of the broadcast source. Interestingly, the time complexity of broadcast in the

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case of level separable networks does not directly depend on the network size which makes the study of level separable networks of independent interest.

We further investigate the hardness of determining if an arbitrary network topology is level separable. Our study shows that even though checking that a separation is a level separation or build a level separable network can be done in polynomial time, determining that a graph has the level separable property is **NP-complete**. This result opens interesting independent research directions. We also improve in terms of memory complexity the broadcast scheme with acknowledgment proposed in [EGMP19]. Our solution does not use extra local persistent memory except the 3-bits labels. Our optimization improves original proposition in [EGMP19] in terms of memory complexity for arbitrary networks. Due to the page limitation, please see [BPR19] for details.

2 System and Model

In wireless networks, broadcast ensures that once a **source node** (a.k.a. the broadcast initiator) sends a message, then all other nodes in the network should receive this message in a finite time. Limited by the transmission range, messages may not be able to be sent directly from one node to arbitrary nodes in the network. Therefore relay nodes are needed to assist the source node during the message propagation by re-propagating the message. An **acknowledgement**, *ACK* message, sent from one of the last nodes receiving the broadcast message, may be necessary to inform the source node to trigger next action. When a message is sent from a node, it goes into the wireless channel in the form of a wireless signal which may be received by all the nodes within the transmission range of the sender. However, when a receiver node is located within the range of more than one node who send messages simultaneously, the multiple wireless signals may generate **collisions** at the receiver. The receiver cannot decode any useful information from the superposed interference signals.

We model the network as a *graph* $G = (V,E)$ where V, the set of *vertices*, represents the set of **nodes** in the network and E, the set of *edges*, is a set of unordered pairs $e(u,v)$, $u,v \in V$, that represents the **communications links** between nodes u and v. Let $d(u)$ be the set of **neighbors** of node u, where $\forall v \in d(u), e(u,v) \in E$. Let the **level** of node u $l(u)$ be the geographic distance between u and s, where s is the source node. Let $S(u)$ ($P(s)$) be the set of **sons** (**parents**) of u. $v \in P(u)$ ($S(u)$), if $e(u,v) \in E$ and $l(u) - l(v) = 1$ ($l(v) - l(u) = 1$). Let D be the eccentricity of the broadcast initiator, (i.e., the maximum level of the network).

We assume that the network is connected, i.e., there is a path between any two nodes in the network. And also we assume that nodes execute the same algorithm and are *time synchronized*. The system execution is decomposed in *rounds*. When a node u sends a message at round x, all nodes in $d(u)$ receive the message at the end of round x. Collisions occur at node u in round x if a set of nodes, $M \subseteq d(u)$ and $|M| > 1$, send a message in round x. In that case it is considered that u has not received any message.

3 Level-Separable Networks

We say that an arbitrary network $G(V,E)$ is a Level-Separable Network if the underlying communication graph of the network verifies the *Level-Separable* propriety as described : There exist sets $S_{i,1}$ and $S_{i,2}$, called the *level-separable subsets* of S_i, where S_i is the set of all vertices in the same level i of G, such that $S_{i,1} \cap S_{i,2} = \varnothing$, $S_{i,1} \cup S_{i,2} = S_i$. G verifies the Level-Separable property if there exists pairs $(S_{i,1}, S_{i,2})$ $\forall i > 0$, such that : $\exists j \in \{1,2\}$ that $|P(u) \cap S_{i,j}| = 1$, $\forall u \in F_{i+1}$, where $F_i = \{u \mid u \in S_i,\ l(u) = i \wedge |P(u)| > 1\}$ i.e., for every vertex u at level $i+1$ having multi-parents at level i, u has exactly one parent in $S_{i,1}$ or $S_{i,2}$.

Note that a level-separable network is not necessary a tree network. However a tree is always a level-separable network : the root of the tree is the source node s who begins the broadcast. In a tree topology all non-source nodes have only one parent, i.e. $\forall u \in V - s$, $|P(u)| = 1$, which means that for each i, $F_i = \varnothing$. Hence, with all $S_{i,1} = \varnothing$ and $S_{i,2} = S_i \setminus S_{i,1} = S_i$, the Level-Separable property is therefore verified.

Studies conducted in wireless body area networks (e.g., [BPB17b], [BPB17a]) show that various postural mobilities can be modelled as graphs that fit our definition of level-separable network.

4 Broadcast without ACK in Level-Separable Networks

In this section, we propose a broadcast algorithm β^{LS} with 1-bit labelling scheme λ^{LS} for level-separable networks, that terminates in $2D$ rounds. Each node, j, has a label X_j.

λ^{LS} works as follows :

1) Separate the given level-separable network at each level i into $S_{i,1}$ and $S_{i,2}$, that verify Level-Separable property.

2) Set $X_j = 1$ for node j in $S_{i,1}$.

2) Set $X_j = 0$ for node j in $S_{i,2}$.

β^{LS} works as follows :

1) Source node sends message μ at round 0.

2) If node j with $X_j = 1$ receives message μ for the first time, it re-sends message μ at round $2i-1$, where i is the level ; do nothing, otherwise.

3) If node j with $X_j = 0$ receives μ for the first time, it re-sends μ at round $2i$; do nothing, otherwise.

The main idea of β^{LS} is that, nodes in each level i separated into two different sets S_1 and S_2, transmit their received messages μ in different execution rounds to reduce the collisions impact at nodes in level $i+1$. According to Algorithm β^{LS}, the message μ will be propagated from level to level. Each propagation from a level to the next one takes two execution rounds. In the first round all nodes in $S_{i,1}$ send the received message μ. At the end of this round all the nodes that are the sons of nodes in $S_{i,1}$ receive μ, without collision. As sons of nodes in $S_{i,1}$ contain all the nodes at level $i+1$ who have multi-parents, that means it remains only nodes at level $i+1$ who have only one parent that haven't received message μ yet. In the second round, all nodes in $S_{i,2}$ send μ, and the remaining part of the nodes at level $i+1$ can therefore receive μ from their unique parent. So that after these two rounds of transmission from level i, all the nodes at $i+1$ can successfully receive the message μ. It takes therefore $2D$ rounds to finish the broadcast. See [BPR19] for the detailed proof. Note that nodes will only send once according to β^{LS}. Therefore the algorithm terminates. We propose Theorem 1, see [BPR19] for the detailed proof.

Theorem 1. *Algorithm β^{LS} with 1-bit constant Labelling Scheme λ^{LS} implements broadcast in a level-separable network within $2D$ rounds.*

5 Broadcast with ACK in Level-Separable Networks

By applying β^{LS} and λ^{LS}, the broadcast without ACK finishes within $2D$ rounds, in a level-separable network. In the following, we propose a broadcast algorithm with ACK β^{LS}_{ACK} with a **half way acknowledgement** mechanism using 2-bits labelling scheme λ^{LS}_{ACK} for level-separable networks, that terminates in $2D$ rounds. Each node, j, has two labels X^1_j and X^2_j.

λ^{LS}_{ACK} works as follows :

1) Separate the given level-separable network at each level i into $S_{i,1}$ and $S_{i,2}$, that verify Level-Separable property.

2) Set $X^1_j = 1$ for node j in $S_{i,1}$.

2) Set $X^1_j = 0$ for node j in $S_{i,2}$.

4) Node j on the shortest way for *ACK* going back from a node at level $\lfloor D/2 \rfloor - 1$ to the source node sets the second bit $X^2_j = 1$. Note that the shortest back way for *ACK* could be chosen offline.

5) The other nodes set $X^2_j = 0$.

β^{LS}_{ACK} works as follows :

1) Source node sends message μ at round 0 ;

2) If node j with $X^1_j = 1$ receives message μ for the first time, it re-sends message μ at round $2i-1$, where i is the level, do nothing, otherwise.

3) If node j with $X^1_j = 0$ receives μ for the first time, it re-sends μ at round $2i$, do nothing, otherwise.

4) Node j with $X_j^2 = 1$ having received μ, sends *pACK* after 2 rounds when it re-sends μ. Then it waits a *Waiting Period*, which is 2 rounds. If it doesn't receive another *pACK* during the waiting period, then it sends *ACK* 2 rounds after the *Waiting Period*; do nothing, otherwise.

5) Node j with $X_j^2 = 1$ that receives *ACK* for the first time at some round r, re-sends *ACK* only once at round $r+2$.

Following the λ_{ACK}^{LS}, a way back path is marked with $X_j^2 = 1$ between source s and an arbitrary node at level $\lfloor D/2 \rfloor - 1$. The idea is that when the message μ propagates to the half-way level of the network, a node at that level will begin the *ACK* transmission processing, so that when the μ reaches to the ending node(s) at level D, the *ACK* message reaches the source s at (almost) the same round. As nodes cannot decide if they are the ones at the half-way of network who should generate and send *ACK* message, we use a *Waiting Period* and an extra *pACK* message. The choix that half way ending node is at level $\lfloor D/2 \rfloor - 1$ makes sure that the *ACK* can be sent back to the source node within $2D$ rounds. Note that nodes will only send (both for data message and ACK message) once according to β_{ACK}^{LS}. Therefore the algorithm terminates. We propose Theorem 2, see [BPR19] for the detailed proof.

Theorem 2. *Algorithm β_{ACK}^{LS} with 2-bits labelling scheme λ_{ACK}^{LS} implements broadcast in a level-separable network. The broadcast terminates in $2D$ rounds. The ACK message is transmitted back to the source at round $2(D-1)$, if D is odd or $2D$, if D is even.*

6 Conclusion

We list in Table 1, up-to-date results for broadcasting in multi-hop wireless network with labelling, in termes of 1) number of bits used as labeling, 2) utilization rate of all the combination of those bits, note that the higher the bits utilization rate is, the more efficient the broadcast algorithm will be in terms of memory, see [BPR19] for detail, 3) broadcast's time complexity. Results in Bold Italic are our contributions.

TABLE 1: Broadcast in multi-hop wireless network with labelling

Network Type	Number of Bits	Bits Utilization Rate	Time Complexity
Arbitrary noACK [EGMP19]	2-bits	100%	2n-3
Level-separable noACK	***1-bit***	***100%***	***2D***
Arbitrary ACK [EGMP19]	3-bits	62.5% (***100%***)	3n-4
Level-separable ACK	***2-bits***	***100%***	***2D***

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